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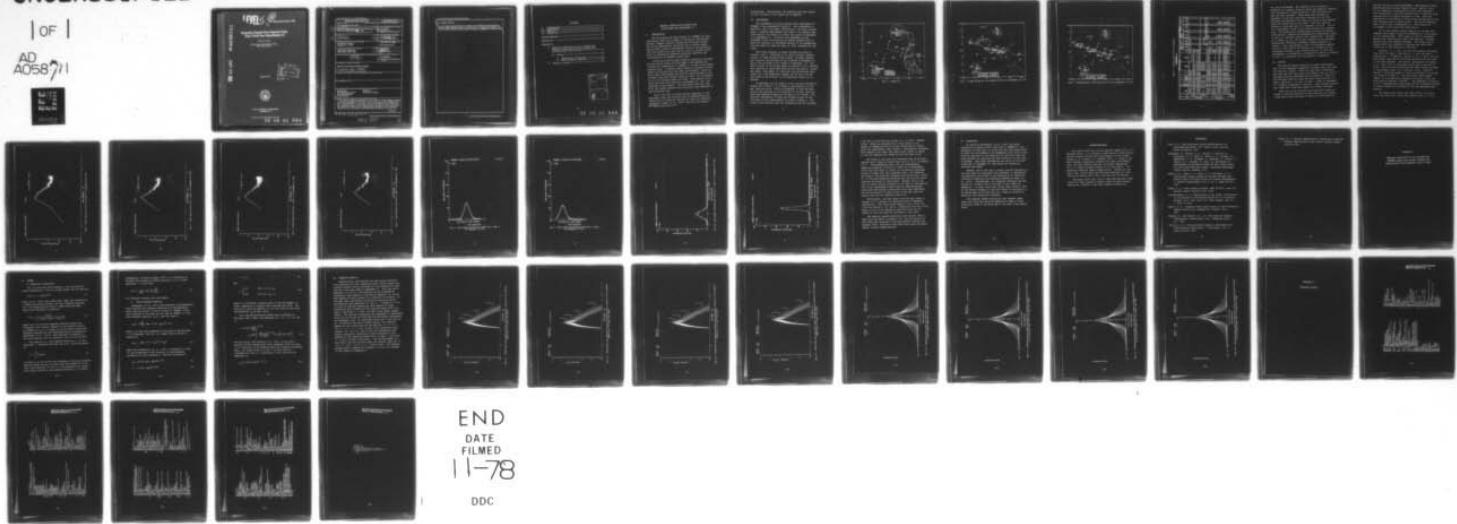
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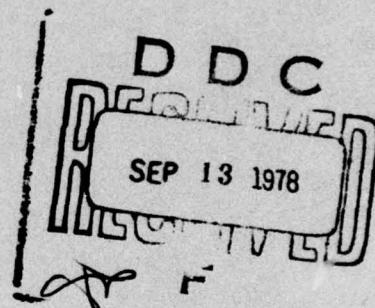
NRL Memorandum Report 3888

## Remotely Sensed Wave Spectra From Joint North Sea Experiments II

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*Space Science Division*

August 1978



NAVAL RESEARCH LABORATORY  
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20. Abstract (Continued)

the lack of strong current gradients in the experiment area, the feasibility of inferring currents by using the technique proposed by Huang, et al. (1972) could not be appropriately investigated. However, this particular technique has been included in this report as an Appendix for reference purposes.

## CONTENTS

I. INTRODUCTION -----	1
II. EXPERIMENTS -----	2
III. RESULTS -----	7
IV. CONCLUSION -----	18
 Acknowledgments -----	19
References -----	20
 Appendices	
A. Numerical Evaluation of the Interaction Between Steady Non-Uniform Currents and Fetch-Limited Gravity Waves -----	A-1
A1 Theory-----	A-1
a. Theoretical Background -----	A-1
b. Wave Frequency Spectrum -----	A-2
B. Computer Program -----	B-1

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REMTELY SENSED WAVE SPECTRA FROM  
JOINT NORTH SEA EXPERIMENTS II

I. INTRODUCTION

The Joint North Sea Wave Project II (JONSWAP II) was a cooperative effort by a number of scientists from Germany, Holland, Denmark, England, Canada and the United States. One of the experimental objectives was to obtain remote sensing data, from an instrumented aircraft simultaneously with the ground-truth data from an array of surface instruments for addressing important questions regarding the interpretation of remotely sensed data.

Scientists from the Naval Research Laboratory and NASA Wallops Flight Center utilized NASA's instrumented C-54 aircraft for observation in JONSWAP II, as one of the remote sensing teams. A typical remote sensing instrument carried aboard the aircraft was the laser profilometer. This air-borne laser profilometer profiled the ocean surface as the aircraft flew with constant velocity and at the altitude of 91.5 or 152.4 meters above the ocean. Wave spectra calculated from wave data obtained on September 19, 1973, are presented in this report. The data were relatively less noisy and steady offshore wind conditions were observed on that particular day.

Due to the lack of strong current gradients in the experiment area, the original goal of demonstrating the feasibility of inferring currents by using the technique proposed by Huang, et al. (1972) could not be properly

Note: Manuscript submitted June 15, 1978.

investigated. Nevertheless, the technique has been worked out and included in this report as an Appendix.

## II. EXPERIMENTS

The placements of in-situ ground-truth instruments of JONSWAP II are presented in Figure 1. The instruments at Stations 4 and 8 are shown, particularly, for their arrangements. Airborne measurements were made in the general area from Station 4 to Station 11 during the period of September 17 to September 27. Of which, only September 18 and September 19 had the condition of steady offshore wind in which the analysis is interested because of its assumptions, the data taken on these two days is, thus, selected for the study.

The flight patterns of these two days are shown in Figures 2 and 3. According to Dr. Walsh (private communication), of NASA Wallops Flight Center, the NASA airplane was flying at the altitude of 152.4 meters on September 18 and at the altitude of 91.5 meters on September 19. The small circles on the flight paths in Figures 2 and 3 indicate the locations at which data from Inertial Navigation System was taken. The symbol "P" indicates that photographs were taken with 70 mm Hasselbold cameras (80 mm lens) out the left side of the aircraft at the depression angles of 45 degrees.

On September 18 over Station 8 the wind was recorded as steady for 14 hours at 13.5 M/sec in the direction of 121 deg. from the north. While on September 19 over the same station the wind was in the direction of 147 deg. from the north and remained steady for 12 hours at 12.5 M/sec. The detailed information on these two flights as well as the available in-situ measurements is listed in Table 1. The dotted lines indicate that the information was not recorded

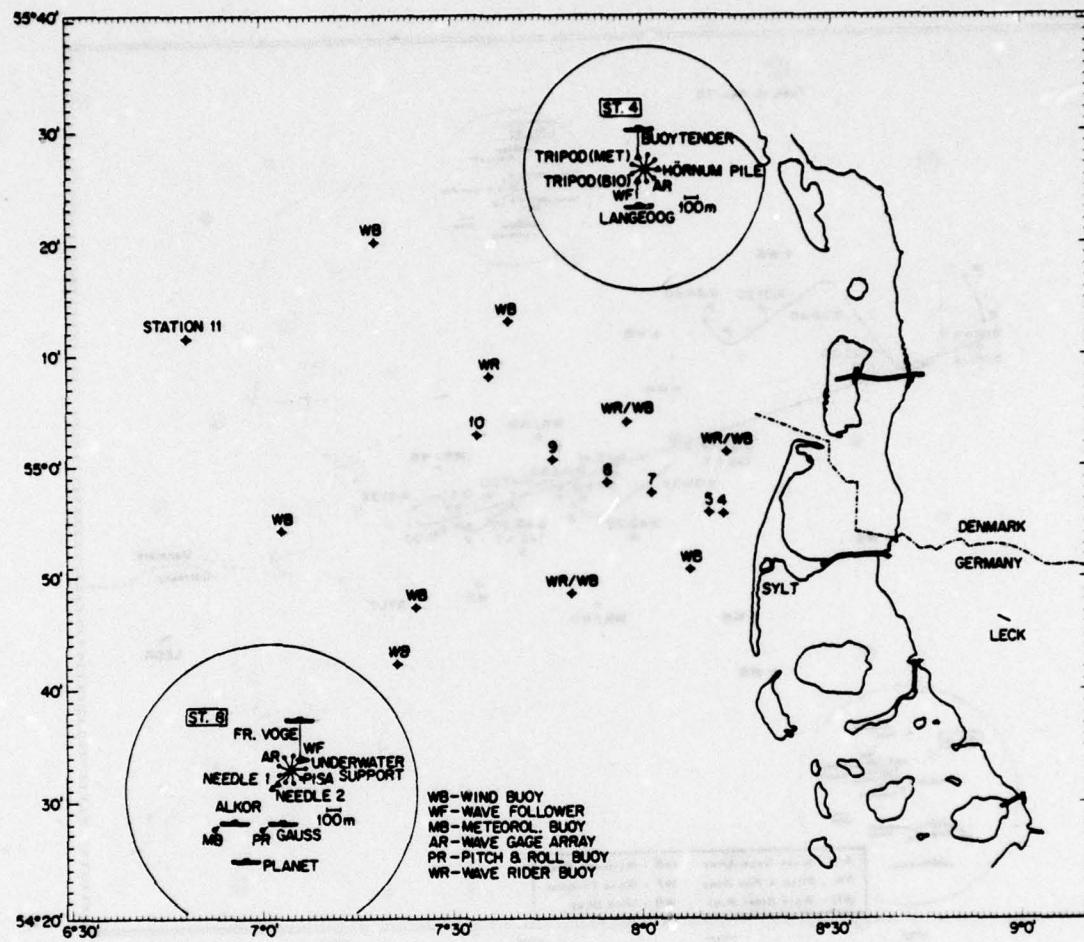


Fig. 1 - JONSWAP II

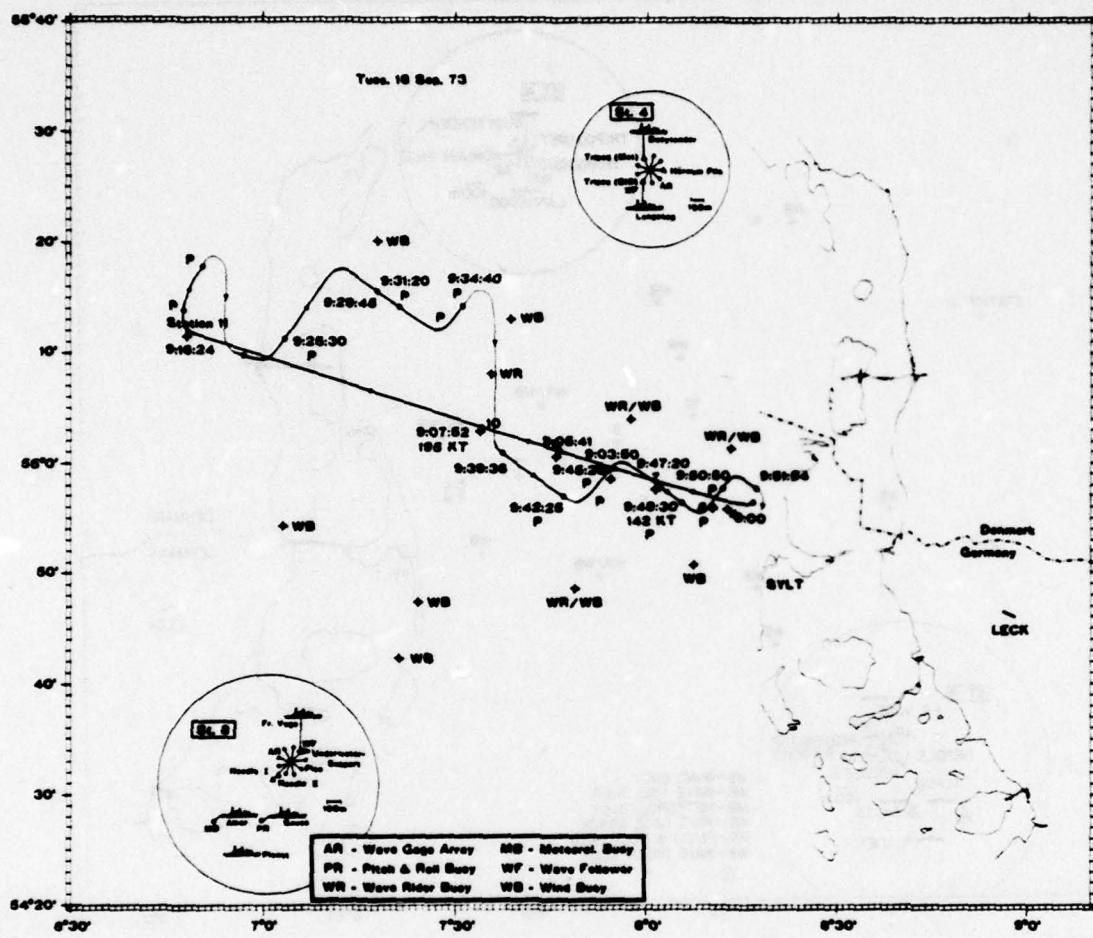


Fig. 2 - Flight pattern at the altitude of 152.4 M on September 18, 1973

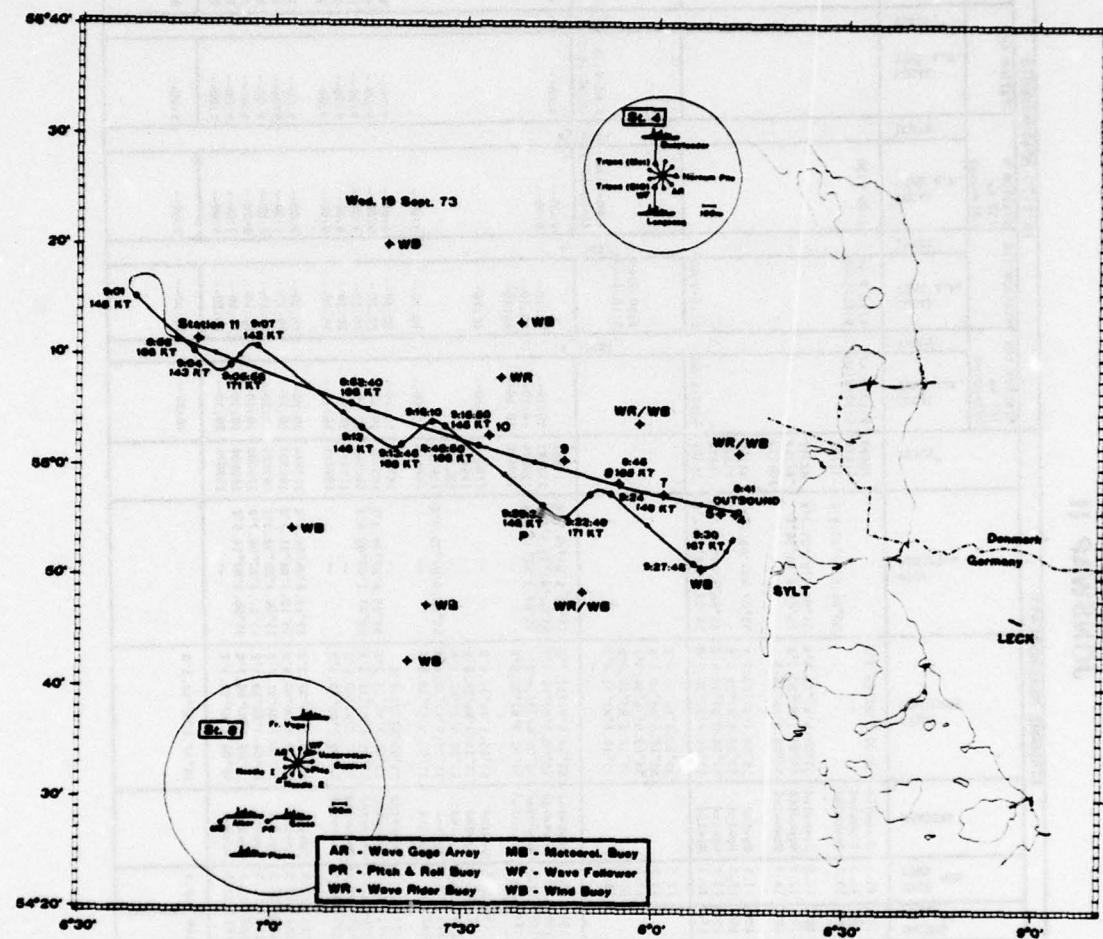


Fig. 3 - Flight pattern at the altitude of 91.5 M on September 19, 1973

Table 1 - Airborne and In-Situ instruments

JONSWAP 11

but can be estimated. The heading of the airplane is presented in a general sense of upwind and downwind, however, this information is used precisely in the calculation as what has been recorded. Three tapes were recorded on September 18 and four tapes were recorded the next day. Excluding calibrations, the files with data of real measurements are listed also in the table. Each file takes 91 seconds of digitized data at a frequency of 90 Hz. The in-situ instruments listed in the table provide wave information. The Institute of Oceanographic Sciences at Wormley, Great Britain, operated the Telemetering Accelerometer Buoys A<sub>1</sub> and A<sub>2</sub> at Stations 10W and 10E, respectively. The Wave Rider Buoys, W<sub>4</sub>, W<sub>5</sub>, and W<sub>6</sub> were operated by the Deutsches Hydrographic Institute at Hamburg, Federal Republic of Germany. Very unfortunately, due to circumstances beyond control at the time of the flights, all of these in-situ instruments provide a very limited quantity of data. As a consequence, no ground-truth information on waves at Stations 10 and 11 is available for the purpose of comparison.

### III. RESULTS

The Spectra-Physics Geodolite 3A Laser Profilometer used in this experiment happened to produce very noisy data for these two flights. There are also clear indications from the data that this laser profilometer lost its lock on the phase shifting mechanism quite frequently. Among all the available data for these two days, data from File 4 of Tape 1 and Files 1, 2, and 3 of Tape 2, taken on September 19, is barely acceptable in quality. After careful examination these four files were chosen for further analyses.

Each file of data contains 8192 digitized numerical values at the time interval of one-ninetieth of a second. A high pass filter was used to filter out the effects of

aircraft motions on the measurements. The numerical filter applied was the so-called "Martin Filter" (Martin, 1957). It is a symmetric, non-recursive filter which features a sine termination to the gain function and a correction which insures unity at a cutoff frequency of zero. The sine termination is introduced to avoid large oscillations in the gain function due to a sharp cutoff. The cutoff frequency used in the filter corresponded to a cutoff period of 10 seconds in this particular application.

Due to the limited storage capacity of the CDC 1604 computer this amount of data was segmented at a time length of 5.69 seconds each. This length in time is considered adequate for obtaining the ocean wave spectrum. Fifteen spectra were then ensemble averaged. The effects due to Doppler shift were removed by assuming that waves were travelling in the direction of the wind.

Figures 4, 5, 6, and 7 are the wave spectra calculated from File 4 of Tape 1, and Files 1, 2, and 3 of Tape 2, respectively. In addition, Figures 8, 9, 10, and 11 are the wave height distribution functions obtained from the files in the same sequence. The vertical coordinates of Figures 4, 5, 6 and 7 are in logarithmic scale and in the unit of  $M^2/Hz$ . The horizontal coordinates of these figures are also in logarithmic scale, but in the unit of Hz. Figures 4 through 7 show wind speeds in M/sec and fetches in M as well as Figures 8 through 11. The significant wave heights (SWH's) in M as defined by Neumann and Pierson (1966) are also shown in Figures 4 through 7. The abscissas, of Figure 8 to 11, represent wave amplitudes and are nondimensionalized by being divided with variances of the corresponding wave spectra.

The laser noise levels vary from 0.048 M to 0.094 M while the laser noise limits are greater than 3.47, 4.26,

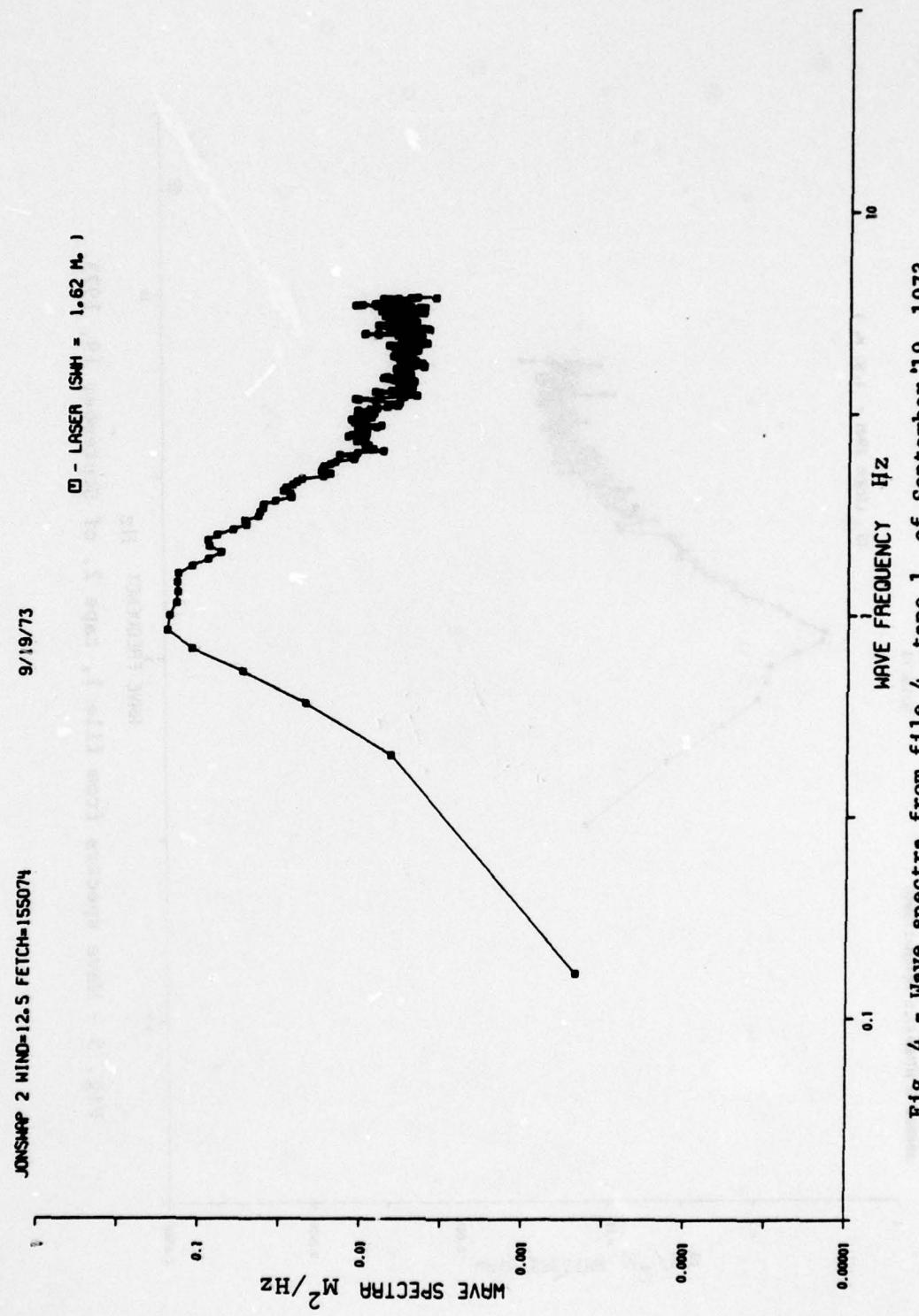


Fig. 4 - Wave spectra from file 4, tape 1, of September '19, 1973

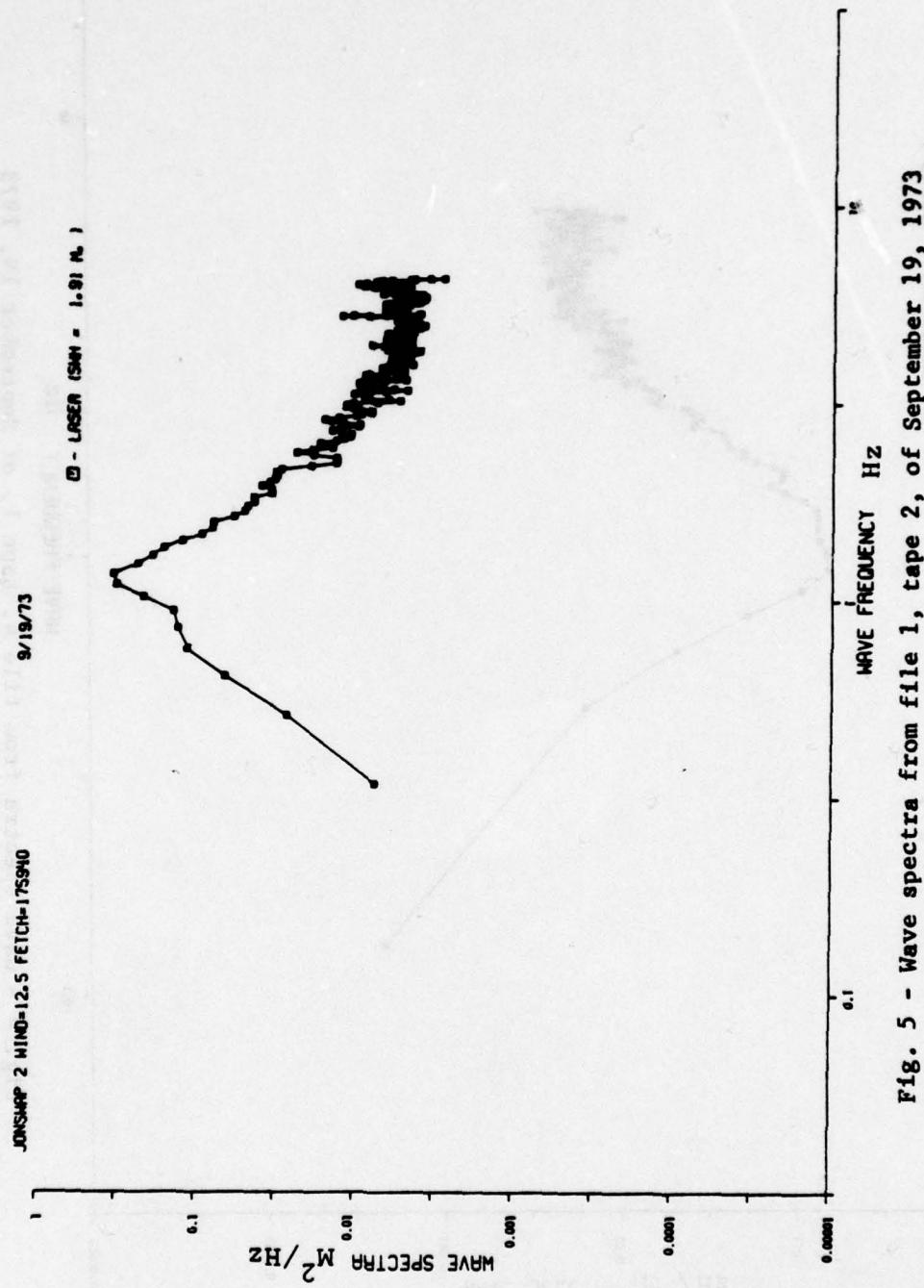


Fig. 5 - Wave spectra from file 1, tape 2, of September 19, 1973

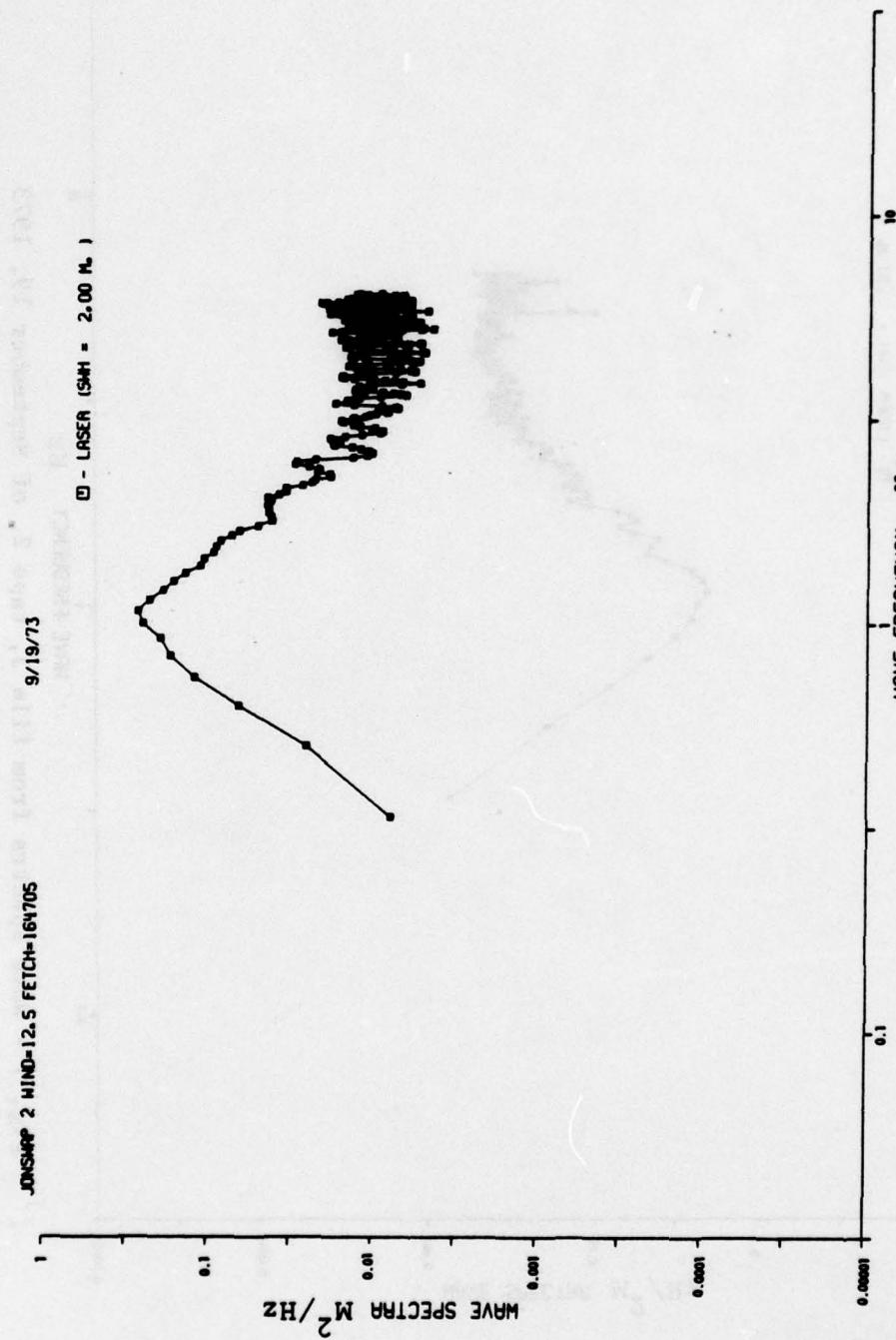


Fig. 6 - Wave spectra from file 2, tape 2, of September 19, 1973

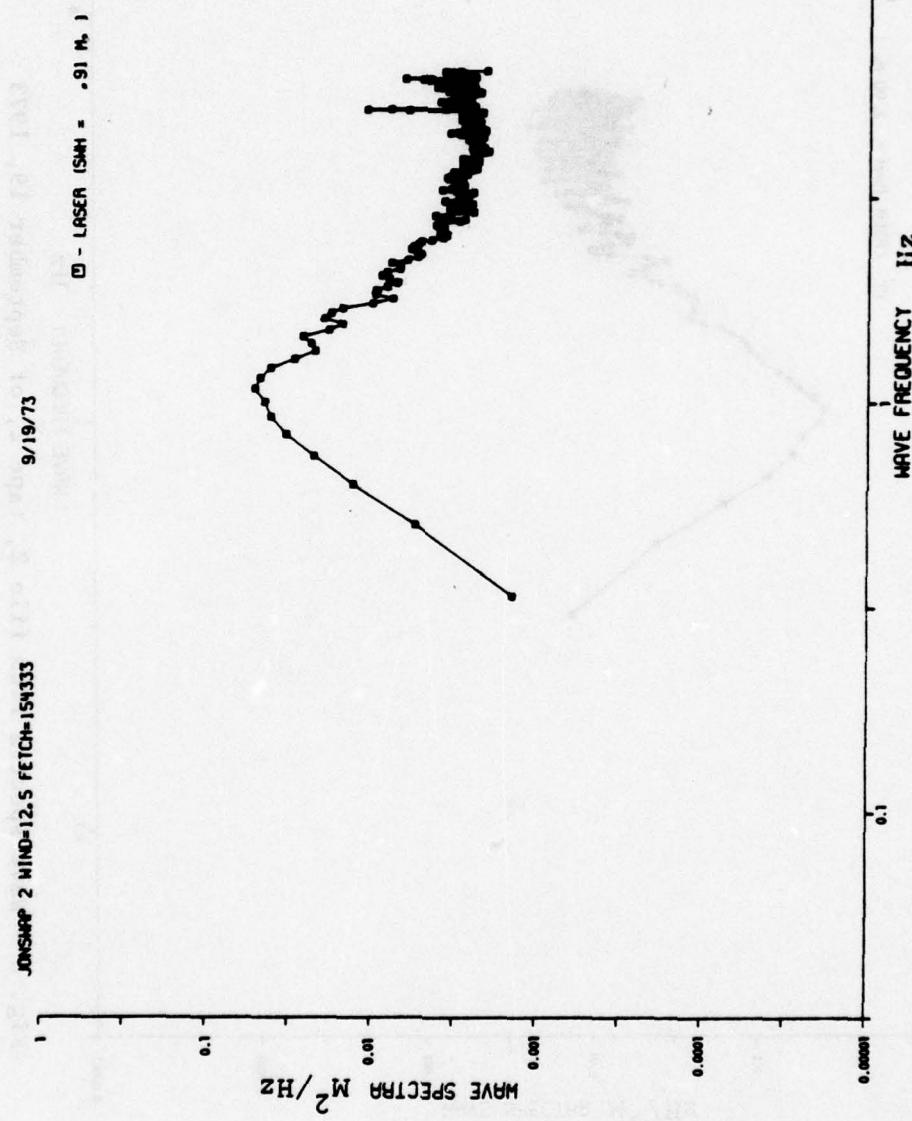


Fig. 7 - Wave spectra from file 3, tape 2, of September 19, 1973

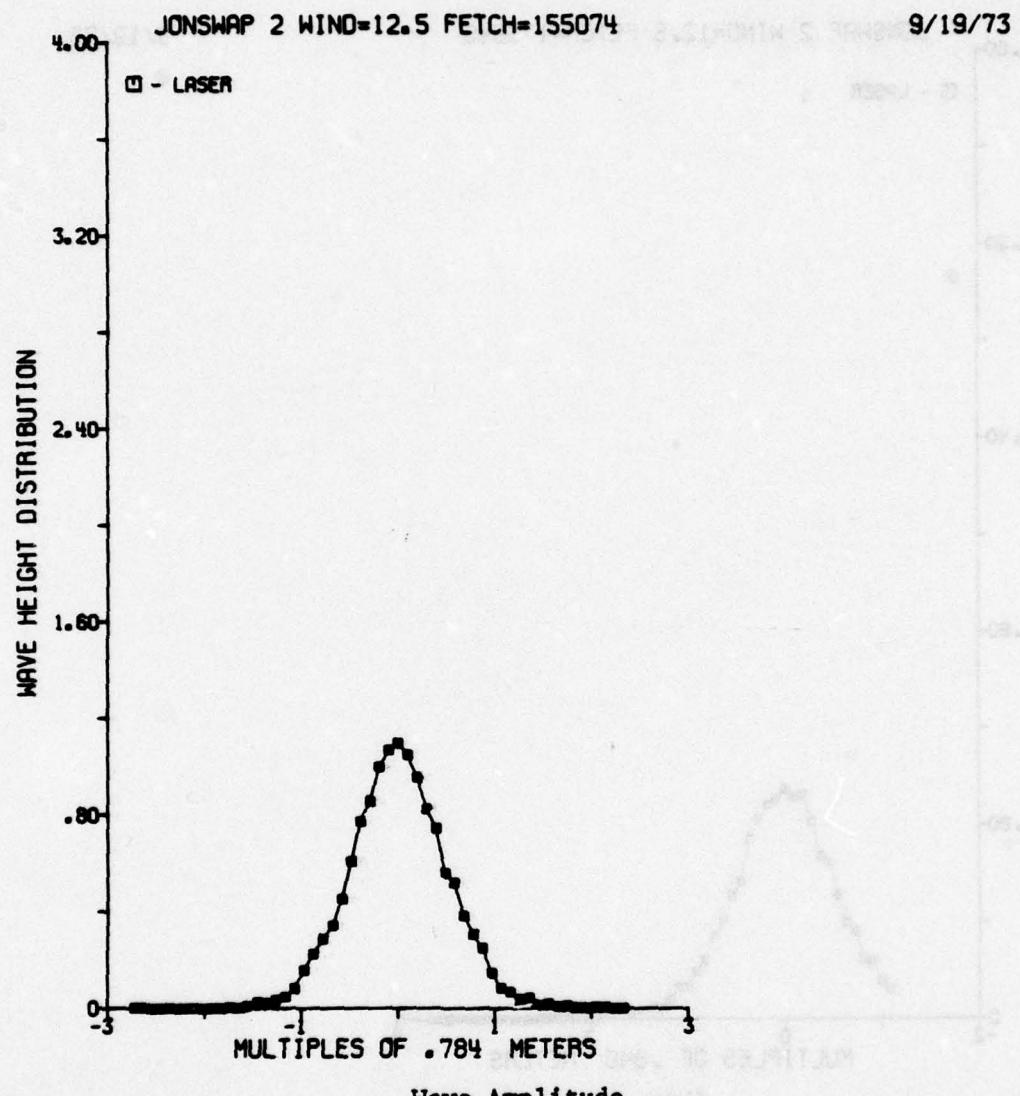


Fig. 8 - Wave height distributions from file 4, tape 1,  
of September 19, 1973

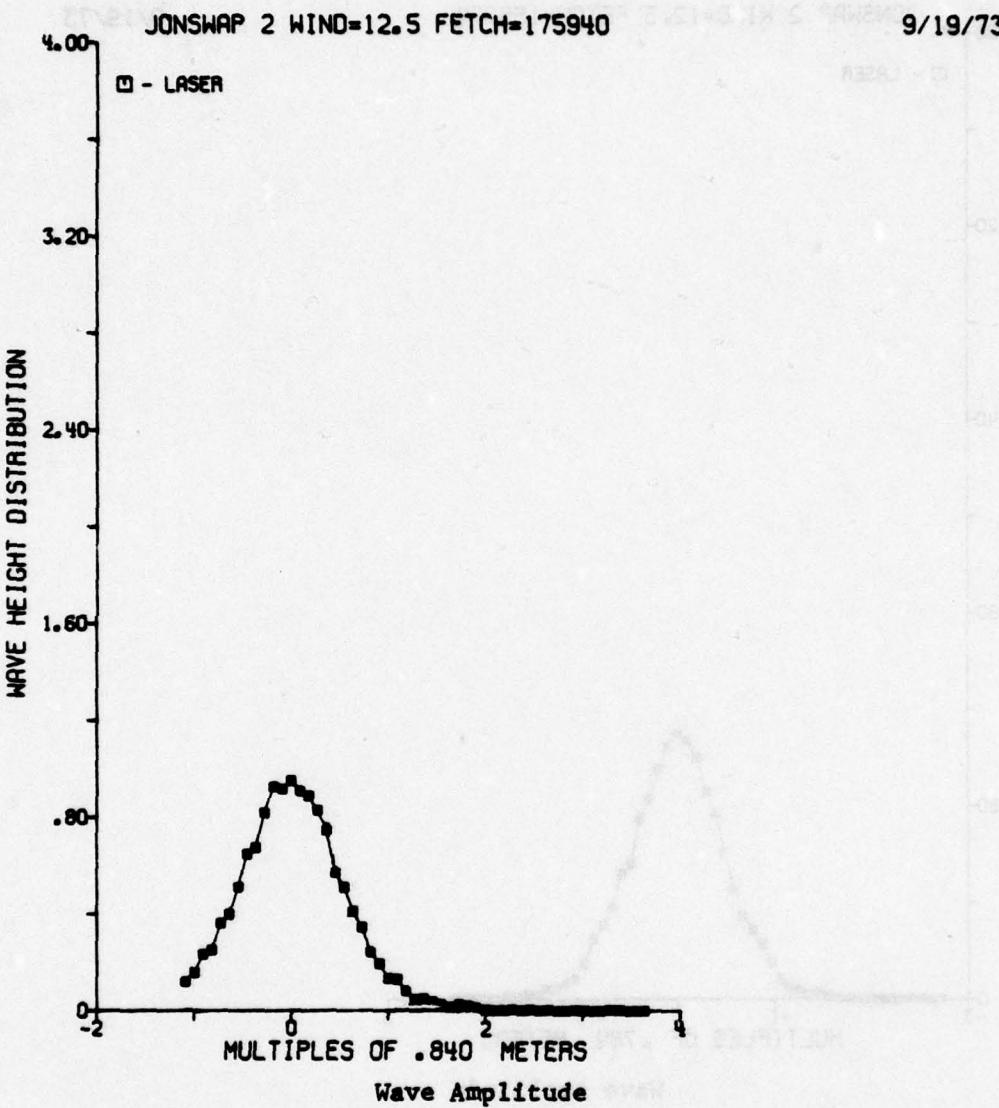


Fig. 9 - Wave height distributions from file 1, tape 2, of September 19, 1973

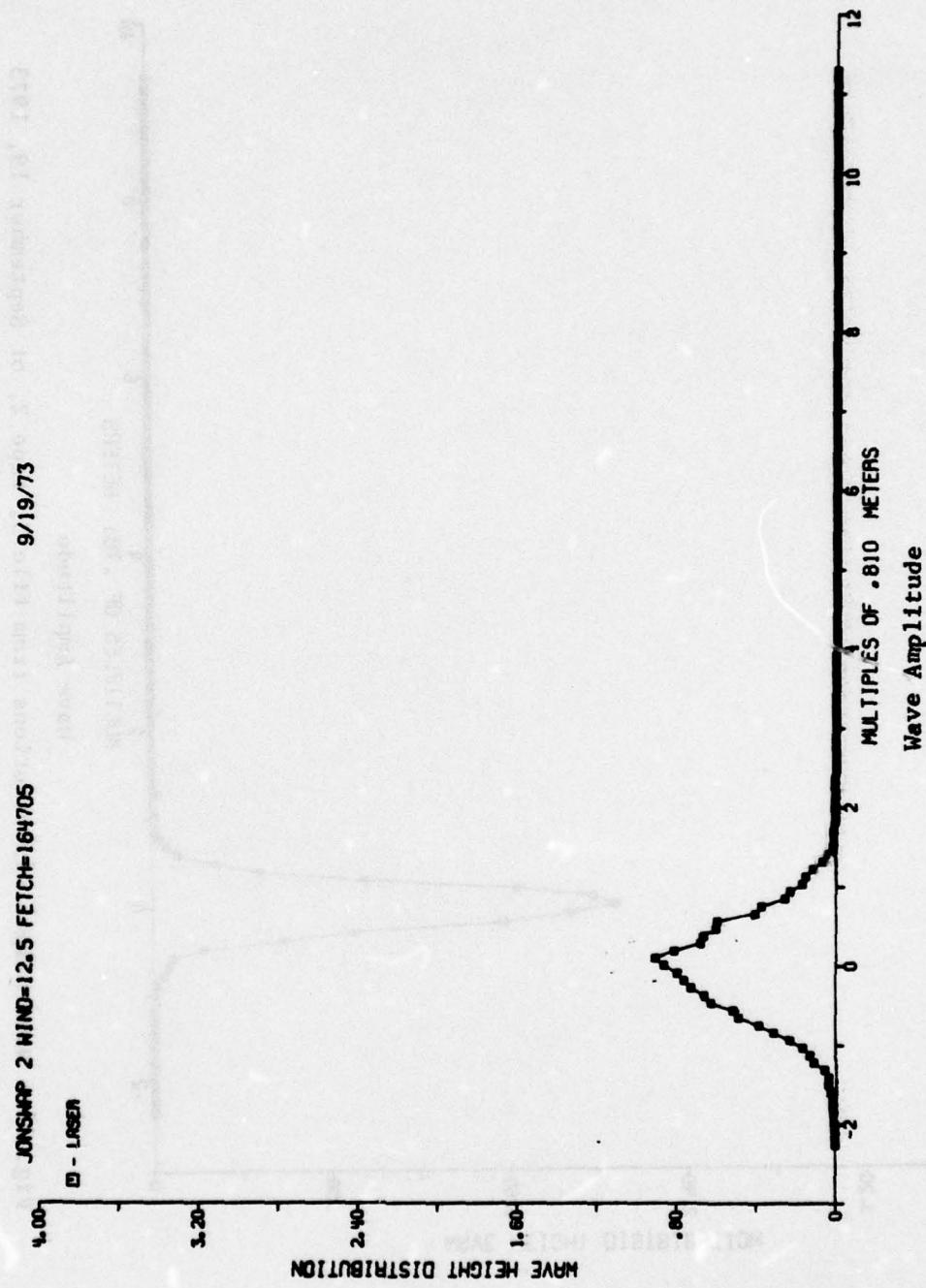


Fig. 10 - Wave height distributions from file 2, tape 2, of September 19, 1973

JONSWAP 2 WIND=12.5 FETCH=154333

9/19/73

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2.40  
1.60  
0.80  
0

WAVE HEIGHT DISTRIBUTION

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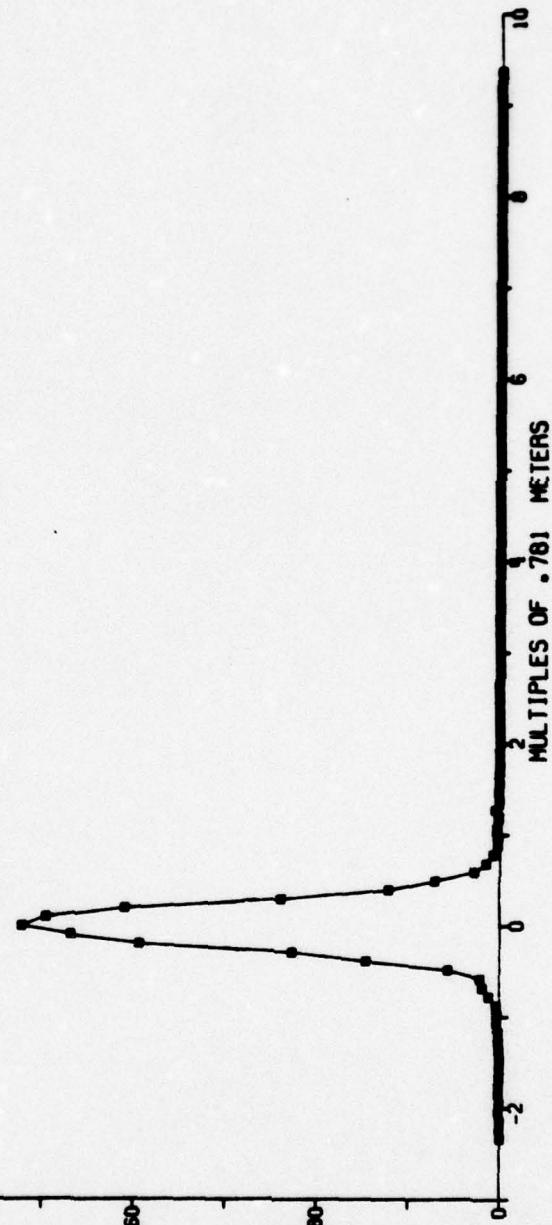


Fig. 11 - Wave height distributions from file 3, tape 2, of September 19, 1973

3.36, and 4.02 Hz shown by Figures 4, 5, 6, and 7, respectively. These are unusually high noise levels at low ranges of frequencies which are the indications of highly noisy and undesirable laser signals. The spectral estimates which appear to be lower than laser noise levels in values at the low frequency are caused by the high pass filter.

The slopes at the high wave frequency ends of the wave spectra show a range of values from -3.25 to -4.71 in Figures 4 to 7. Some mechanisms other than the wave-breaking mechanism suggested by Phillips (1958) and Kitaigorodskii (1961) must have been in control of the physical processes as well at these high wave frequency ends. For otherwise the slope at the high wave frequency end should show a value of 5 if the wave-breaking mechanism were the only one which controls the growth of these waves. However, due to the lack of strong current gradients in the area as indicated by the in-situ measurements there might be some mechanisms other than wave-current interaction which were responsible for the variations of slope values at the high wave frequency ends from the expected value of -5.

Nevertheless, the wave height distributions shown in Figures 8 to 11 display the characteristics of Gaussian distribution. The values shown beyond 2.1 M, 2.03 M, and 1.95 M in Figures 9, 10, and 11, respectively are due to the drops of bits in the recording tapes which are not the results of the real physical processes in the ocean.

The remotely sensed significant wave heights (SWH's), which are also shown in Figures 4 to 7 and are defined as four times the variances of the wave spectra (Neumann and Pierson, 1966), agree well with those from visual estimates (Walsh, private communications).

#### IV. CONCLUSION

As stated by Hasselmann, et al. (1973) for waves generated by offshore wind at the site of JONSWAP II, the assumption of deep water is valid only for wind speeds below 25 M/sec and the assumption of homogeneous wave field in the direction parallel to the shoreline is valid only when the angle between the shoreline and wind direction is less than 30 degrees. Both these assumptions are valid for the wind conditions on September 19, upon which the theoretical analyses were based.

However, due to the lack of strong current gradients in the area where the experiment was performed, no appropriate investigation can be done on the feasibility of inferring currents by employing the technique proposed by Huang, et al. (1972). Nevertheless, this proposed technique has been worked out in detail and is included in this report as Appendix A. An area, with known strong shear current, such as the western boundary of the Gulf Stream is desireable to be established as the test site for inferring currents by employing this particular technique.

The remotely sensed significant wave heights (SWHs) agree well with what would be expected for SWHs at those particular areas in the North Sea at the time of the experiments.

#### ACKNOWLEDGEMENTS

The author would like to give special thanks to Mr. J. T. McGoogan and Mr. H. R. Stanley of NASA Wallops Flight Center, Wallops Island, Virginia for encouragement in this study. Messrs. E. A. Uliana, D. L. Hammond, and K. J. Craig of the Naval Research Laboratory recorded the laser profilometer data, and their efforts and help are highly appreciated. Dr. E. J. Walsh provided Figures 1-3 of this report. His generosity deserves special appreciation. Thanks are also due to Mrs. Carolyn Eden and Miss Marie Spangler for their typing and editing and to Mrs. Jean Ware for her drawing.

The author would also like to thank NASA Wallops Flight Center for their financial support under the SR&T Program Contract No. P45823G to the Naval Research Laboratory.

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APPENDIX A

NUMERICAL EVALUATION OF THE INTERACTIONS  
BETWEEN STEADY NON-UNIFORM CURRENTS AND  
FETCH-LIMITED WIND-GENERATED GRAVITY WAVES

## A1. THEORY

### a. Theoretical Background

Let  $n$  be the total wave frequency,  $g$  be the gravitational acceleration,  $U$  be the current speed, and the function

$$R(n) = (1 + 4Un/g)^{1/2} . \quad (1)$$

Huang, et al. (1972) have shown that, under the influence of a steady non-uniform current, the wave frequency spectrum,  $\phi(n)$ , for random gravity waves in deep water and under steady wind conditions is given by

$$\phi(n) = \frac{4\phi_0(n)}{[1 + R(n)] [R(n) + (R(n))^2]} \quad (2)$$

where  $\phi_0(n)$  is the wave frequency spectrum without the influence of the current. Because of the special locality of JONSWAP II,  $\phi_0(n)$  is chosen to be the fetch-limited wave frequency spectrum for wind-generated waves as proposed by Hasselmann, et al. (1973). More detailed information on this wave spectrum will be presented later in this section.

From Equation (2), the standard deviation,  $\sigma$ , of wave amplitude,  $n$ , measured from mean sea level, can be evaluated as

$$\sigma^2 = \int_0^{n_c} \phi(n) dn \quad (3)$$

in which  $n_c$  is the cutoff wave frequency of the wave frequency spectrum taken as that of a wave with wave length of 30 cm. Thus, from Equations (2) and (3), the influence of a steady non-uniform current on the standard deviation,  $\sigma$ , is known.

Subsequently, as done by Huang (1974), it is possible to evaluate the probability density function,  $p(n)$ , of wave amplitude,  $n$ , of the form

$$p(n) = \frac{1}{\sqrt{2\pi}\sigma} \exp\left(-\frac{1}{2} \frac{n^2}{\sigma^2}\right) , \quad (4)$$

for different currents and wind speeds.

b. Wave Frequency Spectrum

Hasselmann, et al. (1973) have proposed a one-dimensional fetch-limited wave frequency spectrum for wind-generated waves from the results of their studies in JONSWAP I which were conducted at the same site as that of JONSWAP II. This wave frequency spectrum,  $\phi_o(n)$ , has the form of

$$\phi_o(n) = \frac{Kg^2}{n^5} \exp[-1.25 (n_m/n)^4] G(n) \quad (5)$$

where  $n_m$  is the wave frequency at the peak of the spectrum,  $K$  is a parameter, and  $G(n)$  is a shape function which is defined as

$$G(n) = \gamma \exp[-(n - n_m)^2/2\xi^2 n_m^2] \quad (6)$$

These four parameters,  $n_m$ ,  $K$ ,  $\gamma$  and  $\xi$  in Equations (5) and (6) are determined by the technique of simultaneously optimizing all four parameters. They are evaluated as

$$n_m = 21.99 (g/W) (gF/W^2)^{-0.33} , \quad (7)$$

$$K = 0.4775 (gF/W^2)^{-0.22} , \quad (8)$$

$$\gamma = 3.3$$

(9)

and

$$\xi = \begin{cases} 0.07 & \text{for } n \text{ in } (0, n_m) \\ 0.09 & \text{for } n \text{ in } (n_m, \infty) \end{cases} \quad (10)$$

where  $F$  is the fetch in meters and  $W$  is the wind speed, in  $m/sec$ , measured at 10 meters above the mean sea level. The value of  $n_m$  given by Equation (7) is very close to the value calculated for  $n_m$  by Chen (1972).

Let  $\beta$  be the equilibrium coefficient as defined by Phillips (1958), then, from Equations (5), (6), (7), (8) and (9)

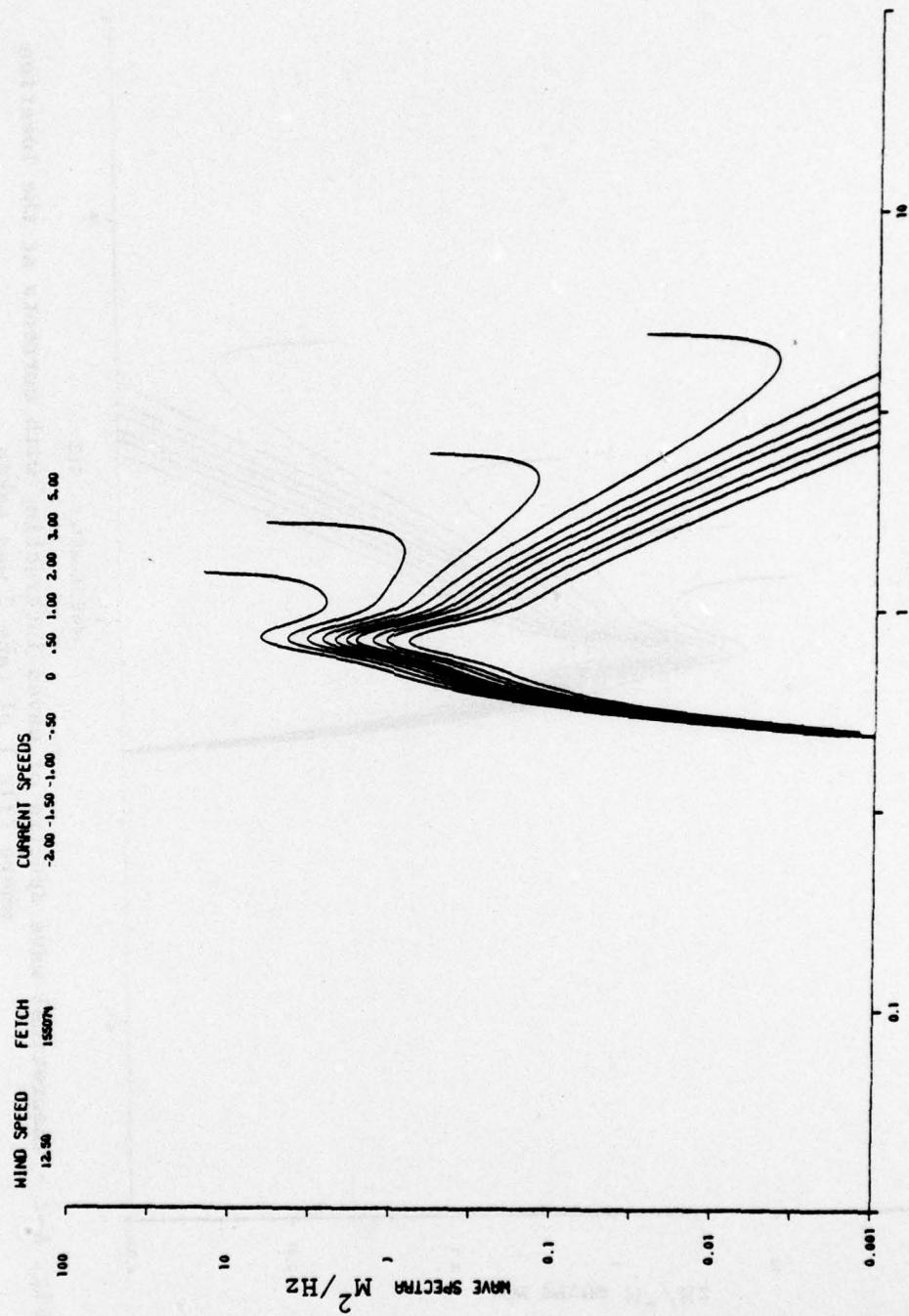
$$\beta = 0.4775 \left( \frac{gF}{W^2} \right)^{-0.22} \cdot 3.3 \exp \left\{ - \left[ \frac{nW}{g} \left( \frac{gF}{W^2} \right)^{0.33} - 21.99 \right] / 967.22 \xi^2 \right\} \quad (11)$$

One can notice, from Equation (11), that  $\beta$  is not only a function of the dimensionless fetch parameter  $gF/W^2$  but also it is a function of the dimensionless wave frequency parameter  $nW/g$ . For fixed values of  $W$  and  $F$ , as the value of  $n$  increases the value of  $\beta$  approaches a limit which can be expressed as

$$\beta = 0.4775 (gF/W^2)^{-0.22} \quad (11)$$

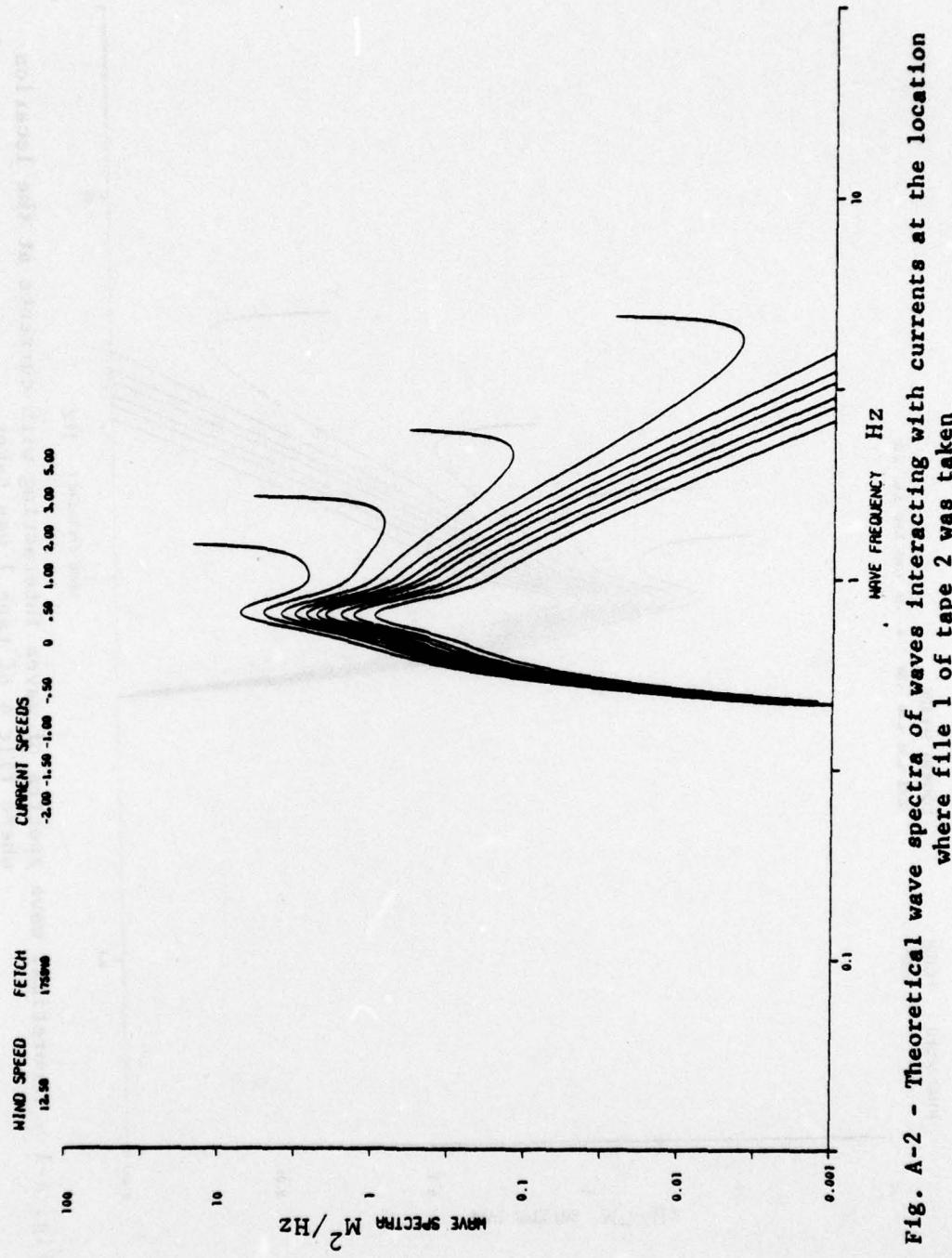
## A2. NUMERICAL RESULTS

Theoretically, wave spectra and wave height distribution functions for wave interacting with various steady non-uniform currents can be evaluated for the locations at which the four files were taken on September 19. With the use of Equations (2) and (5), wave spectra can be evaluated by considering wave spectra in the form of Equation (5) as the wave spectra of waves without the influence of currents. By the same token wave height distribution functions can be evaluated by using Equations (4) and (5). Figures A-1, A-2, A-3 and A-4 show the theoretical wave spectra of waves interacting with currents at the locations where File 4 of Tape 1, and Files 1, 2, and 3 of Tape 2 were taken, respectively. The vertical coordinates are presented in logarithmic scale and in the unit of  $m^2/Hz$  and the horizontal coordinates are presented, also, in logarithmic scale and in the unit of Hz. As shown on the top of these figures, the currents' speeds for the curves from the top down are -2, -1.5, -1, -0.5, 0, 0.5, 1, 2, 3, and 5 m/sec in an increasing order. Figures A-5, A-6, A-7, and A-8 are the theoretical wave height distribution functions of waves interacting with currents at the locations where File 4 of Tape 1, and Files 1, 2, and 3 of Tape 2 were taken. The current speeds for the curves from the top down along the vertical axes are -2, -1.5, -1, -0.5, 0, 0.5, 1, 2, 3, and 5 m/sec. The computer program used to compute for Figures A-1 to A-8 is included in this report as Appendix B.



A-5

Fig. A-1 - Theoretical wave spectra of waves interacting with currents at the location where file 4 of tape 1 was taken



A-6

Fig. A-2 - Theoretical wave spectra of waves interacting with currents at the location where file 1 of tape 2 was taken

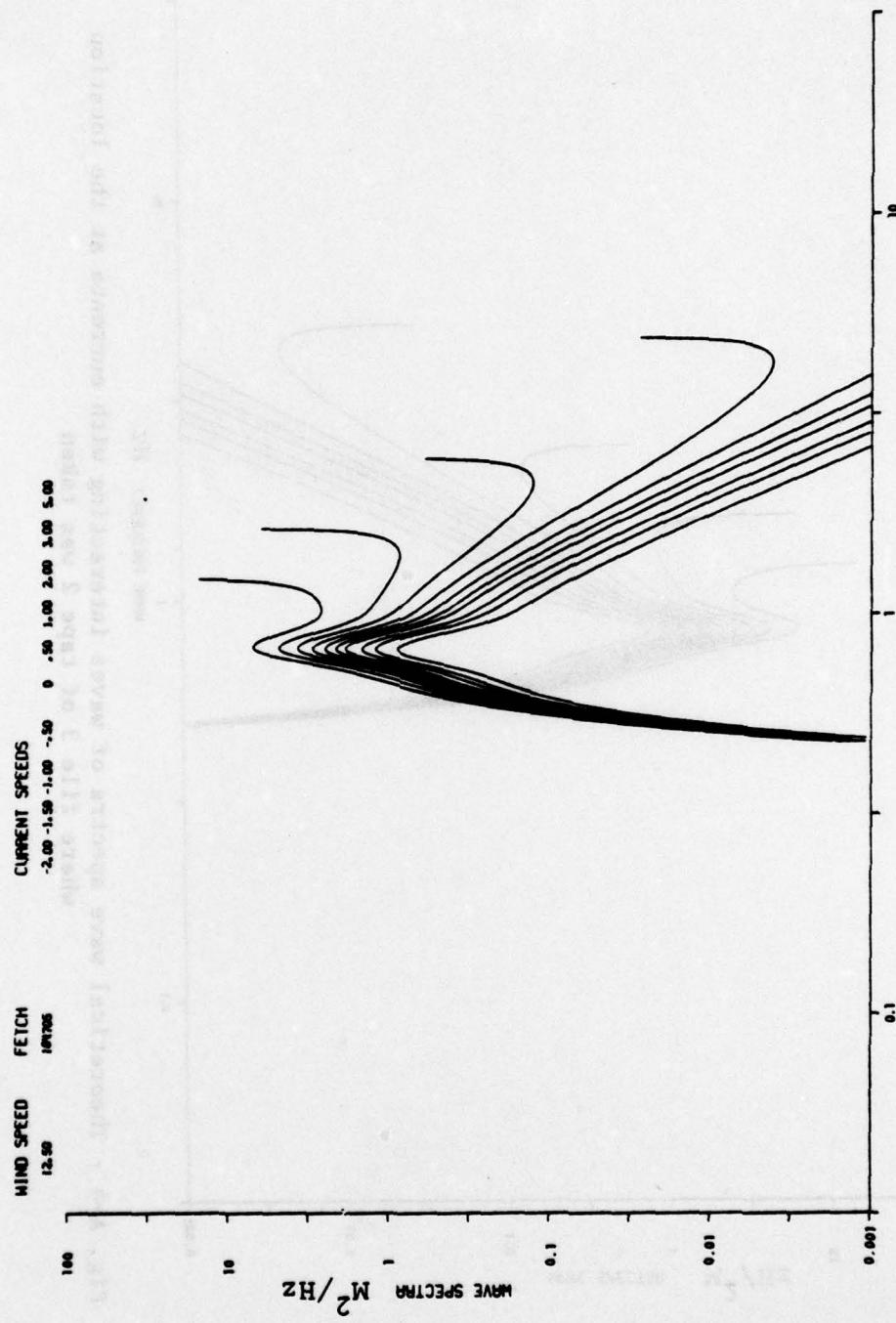
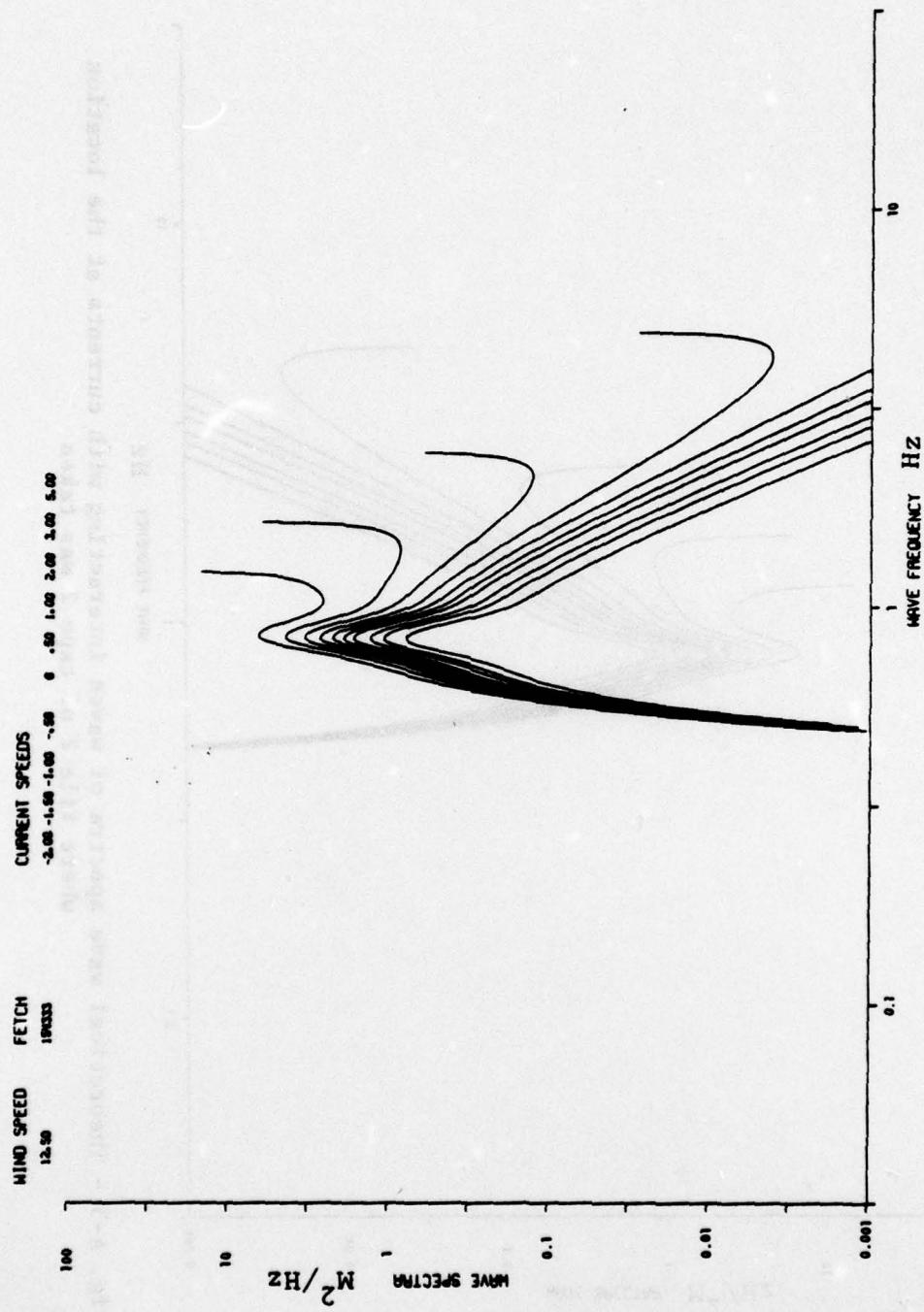
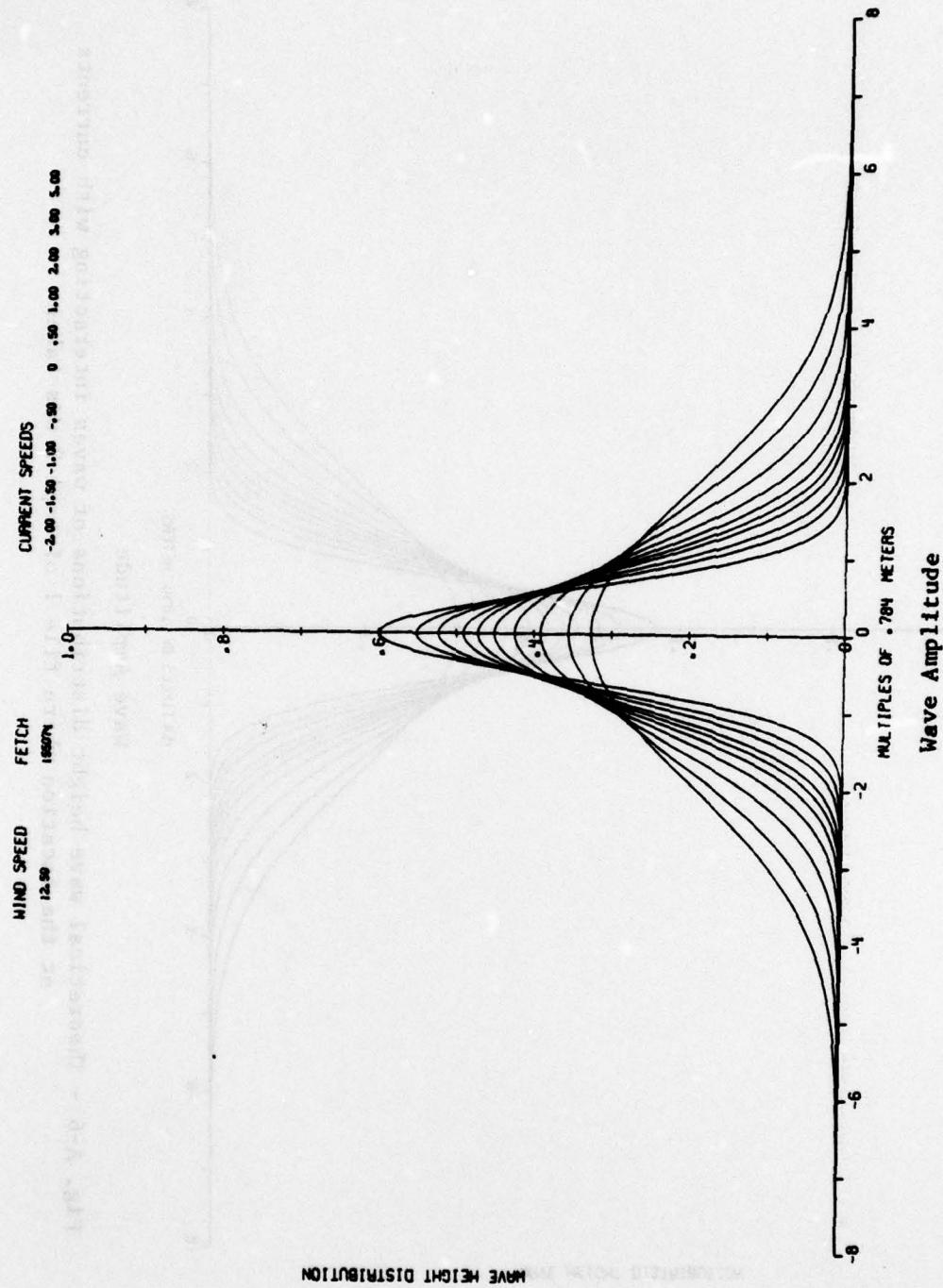


Fig. A-3 - Theoretical wave spectra of waves interacting with currents at the location where file 2 of tape 2 was taken



A-8

Fig. A-4 - Theoretical wave spectra of waves interacting with currents at the location where file 3 of tape 2 was taken



A-9

Fig. A-5 - Theoretical wave height distributions of waves interacting with currents at the location where file 4 of tape 1 was taken

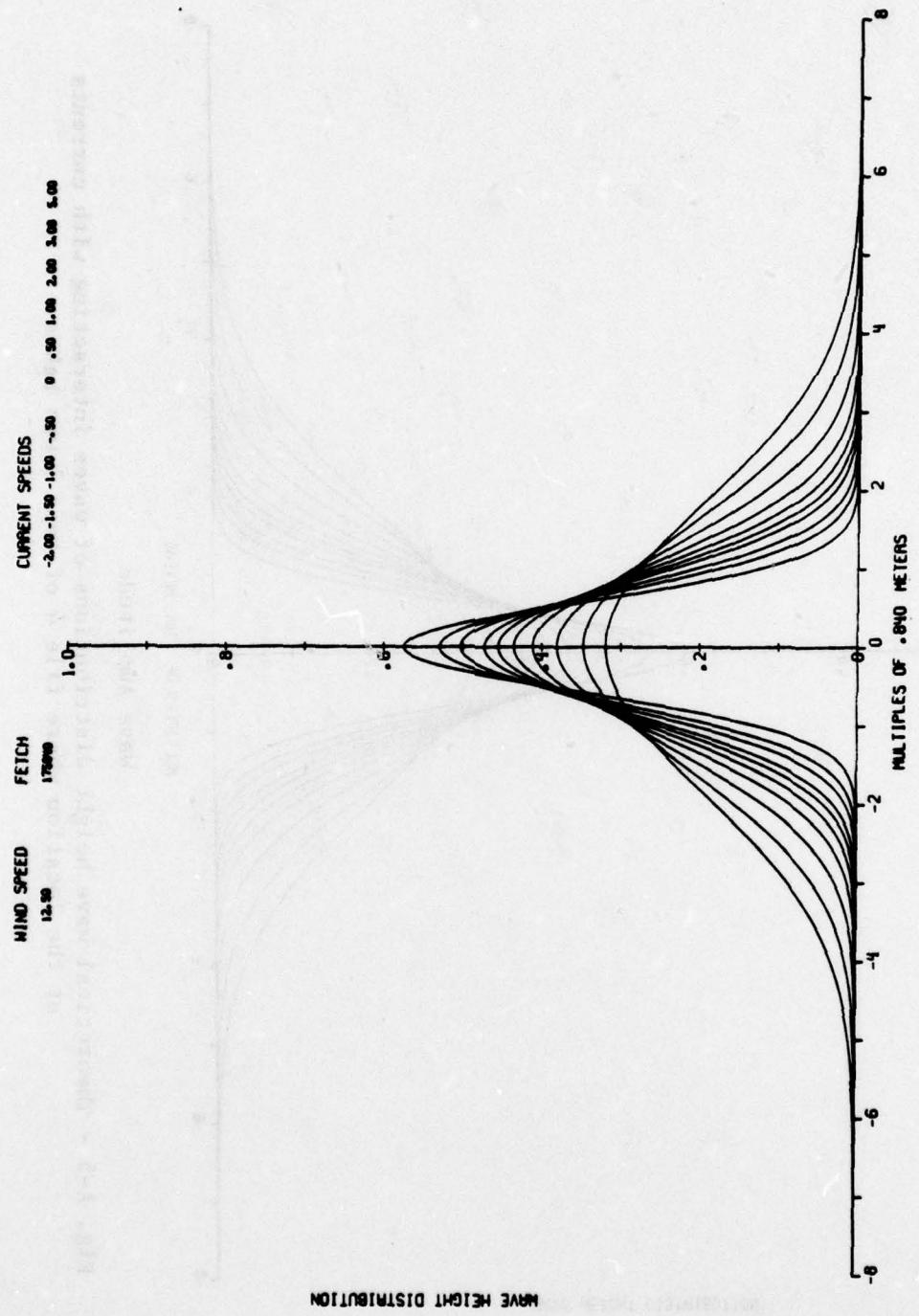


Fig. A-6 - Theoretical wave height distributions of waves interacting with currents at the location where file 1 of tape 2 was taken

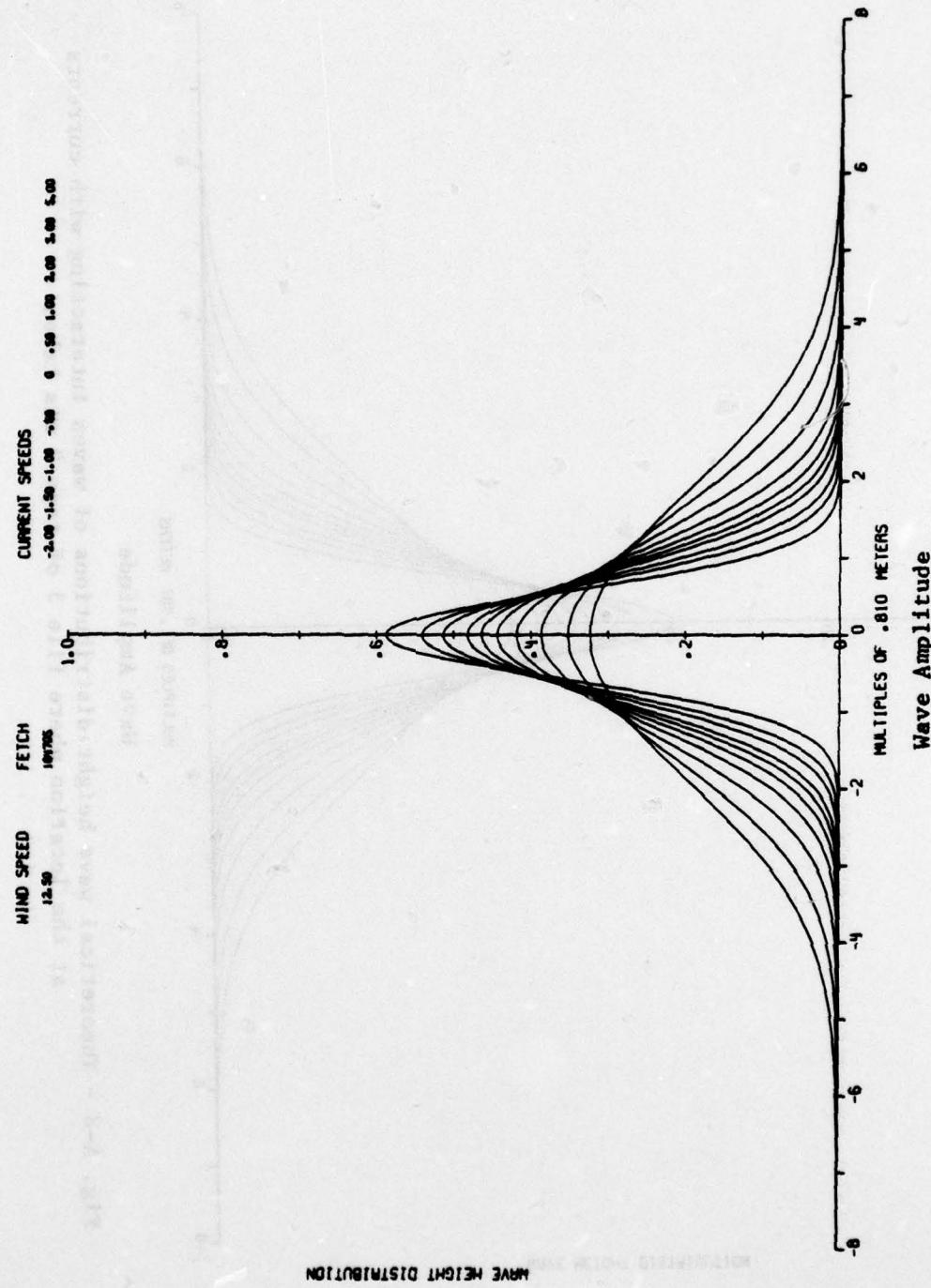


Fig. A-7 - Theoretical wave height distributions of waves interacting with currents at the location where file 2 of tape 2 was taken

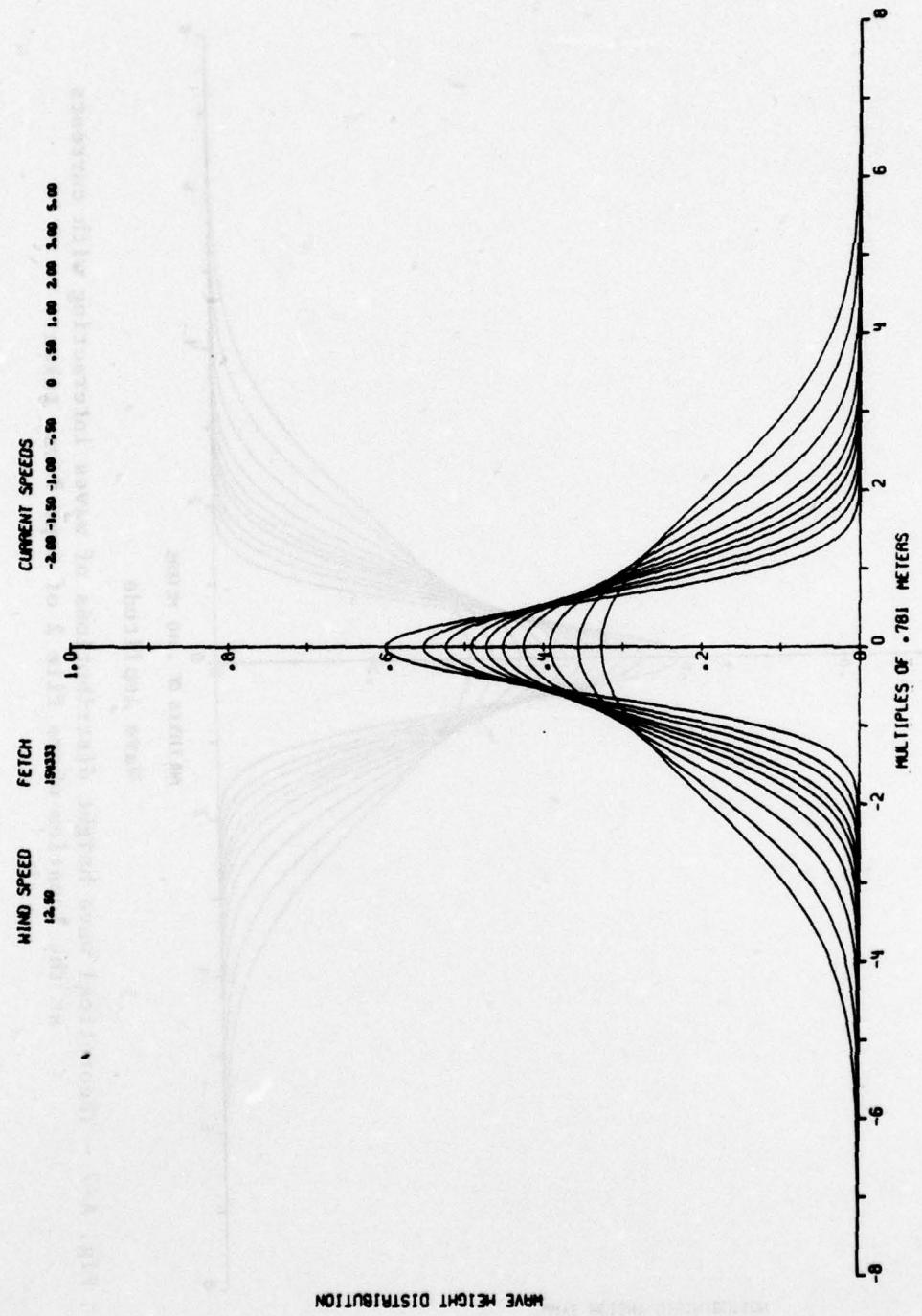


Fig. A-8 - Theoretical wave height distributions of waves interacting with currents at the location where file 3 of tape 2 was taken

APPENDIX B

COMPUTER PROGRAM

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PROGRAM HECK
NFTA = EQUIV INDIUM COEFFICIENT
CUTF = CUT-OFF WAVE FREQUENCY
DELTAN = INCREMENT OR WAVE FREQUENCY
DPP = DIMENSIONLESS FETCH PARAMETER
F(I,J) = J TH FETCH VALUE FOR I TH WIND SPEED
FREQ = TOTAL WAVE FREQUENCY
FREOM = PEAK WAVE FREQUENCY FOR FIXED WIND SPEED AND
FETCH
GA = GRAVITATIONAL ACCELERATION
NFI = NUMBER OF PELTCHES FOR EACH WIND SPEED
NLFPHICL = LIMIT OF THE NUMBER OF INTEGER INCREMENTS
FOR PHICL(K)
NL = NUMBER OF CURRENTS
NW = NUMBER OF WIND SPEEDS
NWF = NUMBER OF WAVE FREQUENCIES
PHICL(K) = WAVE FREQUENCY SPECTRUM WITH THE INFLUENCE
OF CURRENT, L TH CURRENT AND K TH WAVE
FREQUENCY
PX11 = X-ARRAY FOR PLOT
PY11 = Y-ARRAY FOR PLOT
SIGMA(L) = STANDARD DEVIATION FOR WAVE ELEVATION FOR L
TH CURRENT
SIGMA(NM) = STANDARD DEVIATION FOR WAVE ELEVATION FOR
NO CURRENT
SIGNOT = STARTING VALUE FOR PX ARRAY
TITLE(I) = DESCRIPTION OF THE DATA CARDS
U(I) = CURRENTS
W(I) = WIND SPEEDS
X(I) = X-COORDINATE OF THE SYMBOLS FOR CURRENTS
Y(I) = Y-COORDINATE OF THE SYMBOLS FOR CURRENTS
CWHON = W(11)*W(120)*F(111)*P(111)*U(113)*PHICL(31500)*
INLPHICL(31)*SIGMA(13)*X(13)*Y(13)*P(1321)*PY(321)*
2*TITLE(18)*PL(X(321)*PY(321)*PLZ(256)*XS(13)*YS(13)
INTRINSIC CONSTANTS
PAUSE 1
GAS9,R
GAPGAS9?
GAM9=1.3
PTA9=0.07442
ETA9=0.09482
PA11=1.14159
TMD9= 2.0841
DELT9=0.01
DELDF = 0.05
CUTF=1.6
NWF*CUTF/DELTAN
TLOG=LOG(10.0)
FMAX = 15.
FMAY = 10.
FMID = FMAX/2.
FMID = FMAY/2.
FMID = FMAY/2.
XSLEFT = -1.5
XSRIGHT = 1.5
YSTOP = 2.

YSBOTTOM = -3.
YANOR = YROT(TOM1LOG
ANR = FOF(YSANUR)
XSCALF = (XSRIGHT-XSLEFT)/FMAX
YCALF = (YSTOP-YSROTOM)/FMAX
XLEFT = -R.
XRIGHT = R.
YTOP = 1.
XSCALE = (XRIGHT-XLEFT)/FMAX
YCALF = YTOP/FMAX
CALL PLOTSPLZ, 254, 3)
CALL PLOT(11, 2.5, -3)
XSMOT=3.75
DO 10 I=1,13
XSNOT=XSNOT+0.5
XS(11)=XSNOT
Y(11) = FMAY+0.2
10 CONTINUE
XNOT=0.5
DO 30 I=1,13
XSNOT=XSNOT+0.5
XS(11)=XSNOT
X(11)=XNOT
30 V11 = FMAY+0.2
30 CONTINUE
READ-IN INFORMATION
PRINT 500, (TITLE(I),I=1,16)
READ 501, NM(1,W(1),I=1,NW)
READ 502, (TITLE(I),I=1,16)
READ 503, (W(1,I),I=1,NW)
READ 504, (TITLE(I),I=1,16)
READ 505, (TITLE(I),I=1,16)
DO 50 I = 1,NW
NFM = NF(1)
READ 507, (F(I,J),J=1,NF)
50 CONTINUE
DO 60 I = 1,NW
PRINT 503, W(1)
NFM = NF(1)
PRINT 508, (F(I,J),J=1,NF)
60 CONTINUE
READ 509, (TITLE(I),I=1,16)
READ 510, (W(1,I),I=1,NW)
PRINT 511, (TITLE(I),I=1,16)
NFM=14
U1NAE10,00
W2=W(1,W(1))
F9E9M121,99eG9/M(1)
LOOP 450 - FOR DIFFERENT VALUES OF WIND SPEED
DO 450 I = 1,NW
NFVNFM(1,1
DO 440 J = 1,NF
DPPGAS9(1,J)/W2
FREOM2=DFP90.13
FREOM=DFP90.13/FREOM2
FREOM=DFP90.22/FREOM2
BFT1=DFP90.22

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BETA12=0.4775/BETA1
LOOP 109 - FOR DIFFERENT VALUES OF TOTAL WAVE FREQUENCY.
CUT-OFF WAVE FREQUENCY IS 14.30 RADIANS/SEC
FREQ=0,
CALCULATE WAVE FREQUENCY SPECTRUM WITHOUT THE
INFLUENCE OF CURRENT
BETA13=0.4775/BETA1
BETAB=0.4775/BETA1
DO 109 K = 1,10NF
FREQ=PREQ*BETAB*TAN
BETAB*PREQ=0-FREQ
BETA13=BETAB*1.6952
IF (BETAB<1.00) 100,100,101
100 BETAB=BETAB1*1.6744
GO TO 102
101 BETAB=BETAB1*1.6745
102 IF (BETAB>1.00) 1 104,104,103
103 BETAB1=0.
GO TO 105
104 BETAB1=BETAB
BETAB1=0-FREQ (BETA10)
105 BETAB1=1.6745 (BETA10)
BETAB=BETAB1*11
BETAB=BETAB*2
PH12=PREQ*BETAB
PH13=PREQ*BETAB
PH14=PH13*0.64
PH15=PH14*0.64
IF (PH15<-100) 1 107,107,106
106 PH10,
107 PH16=-PH15
PH17=2*XPFP (PH16)
PH1=PH11*PH17*PH12
108 PH1C=PH1*1.6745*THETA1
109 CONTINUE
CALCULATE WAVE FREQUENCY SPECTRA WITH THE INFLUENCE OF
CURRENT
LOOP 130 - FOR DIFFERENT VALUES OF CURRENT
DO 130 L = 1,10NF
FREQ=0.0,
IN 120 K = 1,10NF
FREQ=PREQ*BETAB*TAN
BETAB=0.4775/BETA1
IF (BETA13<1.00) 110,110,111
110 BETA13=0.4775/BETA1
PHIC,K13=0
GO TO 130
111 PHIC2=5*XPFP (BETA13)
PHIC3=(1.6745*BETA13)*(BETA13*BETA13)
PHIC13=(1.6745*BETA13)*(BETA13*BETA13)
112 PHIC3=(1.6745*BETA13)*(BETA13*BETA13)
PHIC13=(1.6745*BETA13)*(BETA13*BETA13)
120 CONTINUE
130 CONTINUE
IN PHIC13=0.0
LOOP 140 - FOR PRINTING WAVE SPECTRA WITH DIFFERENT

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CURRENT
DO 140 L=1,10NF
PRINT 5099, W111(F(1,J))*W111
NEW=XPFP(BETA13)
PRINT 510, (PHIC13,K13)*K13*XPFP(BETA13)
140 CONTINUE

PLOTS OF THE WAVE FREQUENCY SPECTRA
DESCRIPTIONS OF THE PLOTS
CALL PLOT(0,115,0,-3)
YLARLF = XSLFFT
XA = 0.
NHLARL = 7
AXLARL = NHLARLF-1
DXLARL = FMAX/AXLARL
DO 150 IP = 1*NHLARL
CALL NUMBER1=0.25,-0.3,0.1A,1*YLARLF*0.0,ANF=0.1
XA = X*DXLARL
YLARLF=YLARLF+(X*RIGHT-XSLFFT)/AXLARLF
150 CONTINUE
CALL PLOT(1,IP,-0.3,3)
CALL PLOT(1,IP,0.0,3)
CALL PLOT(1,IP,0.0,2)
STICK = 0.
YTICK1 = 0.
YTICK2 = -0.1
DO 160 IP = 1*NHLARL
CALL PLOT(XTICK1,YTICK2,1)
CALL PLOT(XTICK2,YTICK1,2)
XTICK1=XTICK2+DXLARL
160 CONTINUE
110 PLOT(XWAVF,ANF,XPFP(ANF))
YLARLF = YSLDTEN
T = 0.
AXLARLF = NHLARLF
DO 170 IP = 1*NHLARL
CALL NUMBER1=0.7T,0.07,0.14*YLARLF*0.0,ANF=5,2
T = T*DXLARL
YLARLF=YLARLF+(YSLDTEN-YSLDTEN)/AXLARLF
170 CONTINUE
CALL PLOT(1,IP,0.0,3)
CALL PLOT(1,IP,0.0,2)
YTICK1 = 0.
YTICK2 = -0.1
YTICK3 = 0.
YTICK4 = 0.
AXLARLF = AYLARLF+1
DAYLARL = AYLARLF-1
DO 180 IP = 1*AYLARLF
CALL PLOT(XTICK2,YTICK3,1)
CALL PLOT(XTICK1,YTICK4,2)
YTICK2=YTICK4+DAYLARL
180 CONTINUE
CALL SYMBOL(1-0,0,0,0,14,

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110 LOG(WAVE SPECTRA) .0.0-.101
CALL SYMBOL(0.5,FMAY+0.5,0.1,10)IND100,0.0,10)
CALL SYMBOL(2.0,FMAY+0.5,0.1,14,SHETCH0.0,0.5)
CALL SYMBOL(4.0,FMAY+0.5,0.1,14)CURRENT SPEEDS,
10+14)
CALL NUMBER(0.4,FMAY+0.2,0.10,0.61,0.0,4HF5.2)
FETCH(1,1)
TUPU = UPLU
XBLU = XSL1
YBLU = YSL1
UPLU = U11
ALPBLU = ABSP(1,1)
TUPU = UPLU+ALPU
CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
IF (TUPU) 190,190,230
190 DO 200 IP = 2,11,1
ICOUNT = ICOUNT+1
YBLU(XSL1)
UPBLU(1)
ALPBLU = ALSP(1,1)
TUPU = UPLU+ALPU
IF (TUPU) 195,195,210
195 CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
200 CONTINUE
GO TO 255
210 UPLU = U11
CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
DO 220 IC = 1P,11
ICP = IC+1
ALPU = XS1(ICP)
XBLU = XS1(ICP)
YBLU = U11
UPLU = U11
220 CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
TO 255
230 DO 240 IP = 2,4HF
ALPU = XS1(IP)
YBLU = YS1(IP)
UPLU = U11
ALPBLU = ABSP(1,1)
TUPU = UPLU+ALPU
IF (TUPU) 250,250,235
235 CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
240 CONTINUE
GO TO 255
250 UPLU = U11
CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
DO 251 IC = 1P,11
ICP = IC+1
ALPU = XS1(ICP)
YBLU = YS1(ICP)
UPLU = U11
251 CALL NUMBER(1,ALPU,0.10+ALPU,0.0,4HF5.2)
255 DO 290 IP = 1,11

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```
PF14.7)
406 FORMAT(1BA4)
507 FORMAT(1F12.0)
508 FORMAT(12X+10(F7.0,2X)/12X+10(F7.0,2X))
509 FORMAT(1X+1MWIND SPEED,F6.2,X,6MFETCH,F7.0,2X+
14H(100FT SCREEN,F6.2/PX+1THWAVE SPECTRUM)
#10 FORMAT(2X,7(F14.7,2X))
STOP
END
```